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DIGITAL SIGNAL PROCESSING

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Authors: J. B. Thomas and K. Steiglitz, Professors

Date: December 1988

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Departments of Electrical Engineering
and Computer Science

Princeton University

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1. Summary of Research Accomplishments

All of the research results obtained during execution of this grant were reported in journal articles and conference papers, and these are listed in Section 3. (References [1-3] report earlier, related work on the ARO grant of which this is a continuation.) We give here brief summaries of the major contributions; reference numbers are to Section 3.

A. Regularity in VLSI Design [1,3,4,5,9,10,14]

The goal of this work is to exploit regularity in the design of custom VLSI chips. References [1,3,5] treat the problem of efficiently laying out arrays of simple leaf cells, as well as the optimization of these cells. Reference [4] deals with the problem of testing arrays of cells — systolic arrays, for example. References [9,10,14] treat more theoretical questions that arose in the preceding work: especially the problem of testing for cycles in periodic two-dimensional arrays, as well as testing the planarity of such arrays.

B. Architecture for Signal Processing and Regular Computation [2,12,15,18,19,22]

This work explores the practical limits of achieving massive parallelism in regular computation, especially digital signal processing. Reference [2] reports the implementation of a pipeline of identical custom chips for implementing a one-dimensional cellular pipeline. This work was continued in the construction of a pipeline for a two-dimensional lattice calculation — a lattice-gas model for fluid dynamics — reported in [19]. Each of the fabricated test chips is capable of 14 million site-updates/sec. References [12,15,18,22] deal with design limits in large lattice calculations. Limits imposed by communication bandwidth alone are obtained in [12,15]; effects of clock skew in synchronous systems are studied in [18]; the asymptotic performance of self-timed pipelines is studied in [22], which was just completed.

C. Cellular Automata and Regular Computation [7,8,11,13]

Cellular automata are paradigms of regular computation, and have been used as a touchstone for the VLSI and architecture work above. The potential application of cellular automata is explored in this group of papers. References [7,11,13] describe soliton-like behavior in a class of automata, and study the use of these solitons to encode information. The general idea of using such cellular automata for computation is described in [8], as well as the possibility of using analog computation for solving combinatorial problems.

D. Data Communications [6,16,17,20,21]

This work treats digital filter design and some issues that arise in the utilization of linear communication channels. In [6] a new approach to the design of FIR digital filter design is described, based on constraints in the frequency domain, and using linear programming. This work is being continued jointly with J. F. Kaiser (Bell Communications Research), and Steiglitz, Parks, and Kaiser are preparing a documented and tested computer program which will be publicly available. References [16,20] describe a new method of cancelling crosstalk in multi-channel communication

systems. References [17,21] derive bounds on throughput of a linear channel, using a deterministic criterion for discrimination of received signals.

E. Communication Networks [24,29]

Variable length coding schemes are considered for collision-free access to the single broadcast channel [24]. These schemes operate efficiently with a large finite number of users under all traffic conditions. The methods proposed allow the establishment of priority users with short, bounded delay. In [29], a three-state Markov chain is developed to characterize the speech patterns in packet voice communication systems. This model replaces the two-state Markov chain used heretofore and known to be inaccurate.

F. Signal Detection and Estimation [25,27,31,32]

The usual approaches to robust signal estimation and detection restrict the noise densities to be strongly unimodal even though many impulsive noises, both natural and man-made, are known to violate this assumption. In [25] and [32], this restriction is eliminated and robust detectors and estimators are derived and applied to noise environments with heavier than exponential tails. In [31], asymptotic *M*-estimation of mixture constants and local detection in the presence of contaminating distributions are considered. In [27], the robust detection of signals in dependent noise is treated. The solution to the finite-sample problem is obtained with Bayes risk as the performance measure.

G. Matched Filtering [26,30]

Matched filters are an integral part of many detection and estimation schemes and their design under constraint is a problem of considerable importance. In [26,30], an upper bound is derived constructively for the minimum eigenvalue of a correlation matrix which is incompletely specified. The motivation for the study is the desire to achieve robust performance in a matched filter. It is possible to select a signal to achieve optimal performance under worst-case correlation.

H. Density Function Representation [23,28]

A fundamental problem in dealing with signal detection, estimation, or filtering in non-Gaussian noise is the tractable representation of bivariate and higher order density functions. In [28], we consider a generalization of the Mehler expansion for tri- and multi-variate densities. This class can be regarded as a useful generalization of the Gaussian case. In [23], we explore bivariate densities based on the Frechet class of densities. Such densities are simple in form and can be shown to represent accurately a class of two-state noise sources.

2. Participating Personnel

A. Faculty Supported in Part by this Grant:

J. B. Thomas (co-principal investigator)
K. Steiglitz (co-principal investigator)

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C. Chase

C. Ph. D. Dissertations Completed:

1. Kazuo Iwano, "Two-Dimensional Dynamic Graphs and Their VLSI Applications," October 1987.
2. S. Kugelmass, "Architectures for Two-Dimensional Lattice Computations with Linear Speedup," June 1988.
3. D.W. Browning, "Multiple Access Protocols and Flow Control in Computer-Communication Networks," January 1986.
4. P.K. Willett, "Density Representations with Application to Signal Detection," December 1986.
5. D.J. Warren, "Detection and Estimation in the Presence of Uncertainty," June 1987.

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1. K. Iwano, K. Steiglitz, "Some Experiments in VLSI Leaf-cell Optimization," in *VLSI Signal Processing*, (P. R. Cappello et. al., eds.), IEEE Press, New York, 1984, pp. 387-398. (The Proceedings of the IEEE 1984 Workshop on VLSI Signal Processing, Los Angeles, Cal., Nov. 27-29, 1984.)

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